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THE EUCALYPTUS FIBERS AND THE KRAFT PULP QUALITY REQUIREMENTS FOR PAPER MANUFACTURING

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CONTENTS

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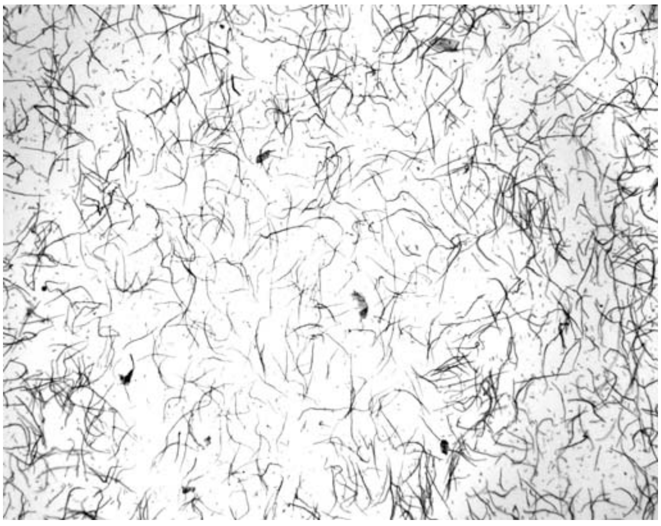
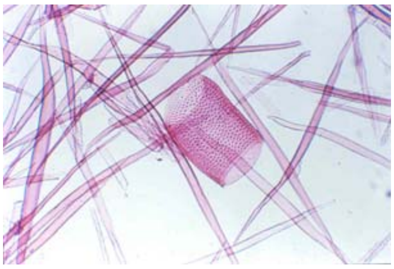
INTRODUCTION

Eucalyptus bleached kraft pulps are rich on fibers, but fibers are not the sole anatomical elements in their contents. Fibers, fiber debris, fines and vessel elements are combined in a rich blend. In a very low pulp consistency, the figure below provides a good idea in relation what we are talking about. This complex blend is usually referred as eucalyptus pulp. On the other hand, there is a relative trend among papermakers to consider eucalyptus pulps as a commodity product, one product that independently from the origin, the performance would be required to be similar. This is an enormous technological mistake. The purpose of this book chapter is to show the potential differences we may find in distinct eucalyptus pulp furnishes for papermaking. Eucalyptus bleached kraft pulps may have very distinct papermaking properties, depending on the wood raw material and on the conditions applied in the manufacture of the pulp (chipping, digesting, washing, screening, bleaching, drying, etc).



Eucalyptus bleached kraft pulp anatomical components
Photo courtesy: Techpap, CTP Grenoble and Regmed



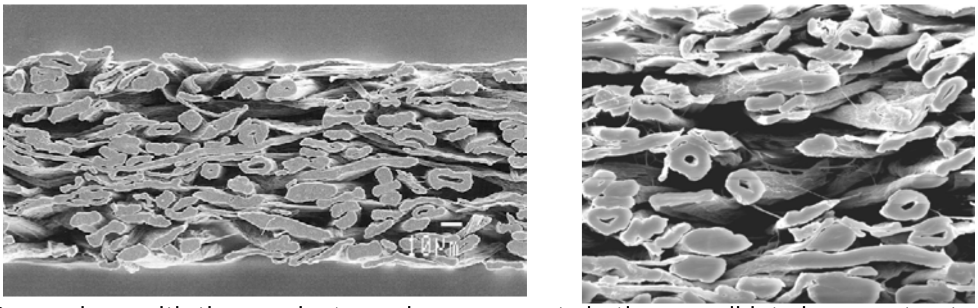
Eucalyptus fibers and vessel element

The papermaking behavior of the pulp depends very much on the anatomical and chemical properties of this mixture, but also in the different pulping and papermaking processes applied to these elements. Fiber morphology and chemical constituents are both very important to allow predictions about pulp behavior in papermaking operations. Fibers consist in the most abundant pulp component. Although their dimensions in lengths and widths are rather similar for different eucalyptus pulps, the cell wall thickness plays important difference. Based on the variations of the fiber morphology and dimensions, there are important characteristics being affected in the paper-machine operation and runnability. Fiber population and coarseness may, up to certain extent, reflect this potential behavior. However, there are other issues to be considered. Fines and fiber deformations are some of them. Fines are important for bonding. A pulp with no fines has poor bonding ability and low strengths. However, excess of fines brings problems in drainage in the wet end section, in dewatering in the press section, and higher density in the paper sheet. Fiber deformations are not natural on fibers, the pulp and paper manufacturing processes create them. Fiber deformations may reduce individual fiber strengths, but they are important to promote bulk and absorbency properties in paper dry sheet. Cell wall integrity and microfibril organization is another issue frequently forgotten. The pulp maker is used to change the pulping and bleaching conditions and he has no indications about the disastrous effects he may eventually be bringing to the fiber wall. The only figure he has is the measurement of the pulp viscosity, very little to really show the damages being happening in the fiber wall. Chemical characteristics of the pulps have also been proved to be important. The hemicellulose content plays important role. In addition to hemicelluloses, fines, fiber population, fiber coarseness and bonding, there are some other important pulp characteristics, such as water retention value, fiber collapsibility, wet fiber flexibility and wet web strength. Moreover, the ability of the fiber to hold water is becoming a critical issue. Fiber charges and hysteresis-associated properties are now being part of a pulp evaluation, due to their potential influence in the paper-machine performance (drainage and dewatering) and final product quality. Pulp quality is, for all these reasons, a group of attributes that may vary according to the eucalyptus wood, the pulping process and with the particular papermaking operations the pulp user has on his hands to utilize this pulp. Pulp quality is so far very dependent on the production chain: it is built along this complete chain.

Eucalyptus pulp bales

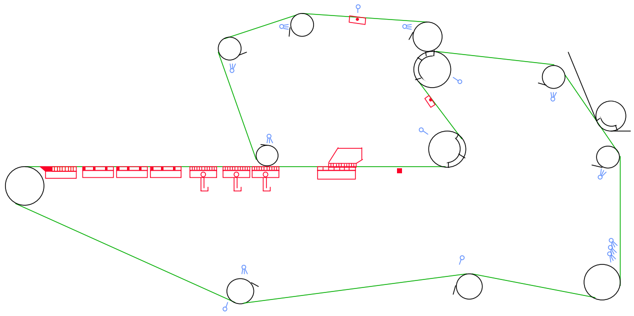
Eucalyptus pulps are recommended for papermaking due to specific properties they impart to paper: bulk, opacity, formation, softness, porosity, smoothness, absorbency, dimensional stability. Faster and more sophisticated machines are being developed to run with these pulps, but the aim is not to lose these paper properties.

All the considerations about pulp quality for papermaking presented in this book chapter are solely related and valid for eucalyptus bleached kraft pulps. We are not making comparisons about different fibrous raw materials or different pulping processes. When comparisons are presented, they are comparing one type of bleached kraft eucalyptus fibers to another one. When high coarseness fibers are suggested for a specific utilization (tissue and filter papers), we are referring to high coarseness eucalyptus fibers (around 9 - 11 mg/100m). Low coarseness eucalyptus fibers are in the range 4.5 - 6 mg/100m. The same to other properties. It has to be understood that other pulp grades, as the high yield eucalyptus pulps have also their distinct advantages and own destination for paper manufacture. However, these pulp and paper properties will be discussed in another book chapter.



Paper views with the eucalyptus pulp components in the consolidated paper structure
(Z direction of the paper)

PAPERMAKING BASIC REQUIREMENTS



Independently in which paper mill we are, the paper sector has as fundamental issues the high productivity, the high operational efficiency (no losses, no problems, no breaks, no stops, no nightmares), the low production costs and the uniform quality in the process and products. It is important to mention that all papermakers have these basic physiological needs, no matter the paper is being made, or the paper-machine is being used. For achieving these targets, the raw material must be as uniform as possible, with characteristics in a narrow range of variation in order not to cause strong impacts in the papermaking process and paper qualities. To tame this variability, the paper mill engineers are used to control a number of pulp quality parameters. However, many times, the selected portfolio of pulp quality specifications does not give a previous idea or a predicted behavior and performance in the pulp utilization, neither in the operation nor in final paper product quality.

When the paper maker asks for uniform pulp, he is not making a request only for brightness, brightness reversion, viscosity and cleanliness. He includes here a number of pulp quality parameters that are very important to his conversion process. His objective is to have a papermaking operation with the minimum variability, without undesirable surprises. The final paper quality must be uniform and within the specification limits, and the losses along the process should be as minimum as possible. When standardization in the pulp intake is demanded by the paper mill manager, he is first trying to guarantee a raw material that may perform well in the paper-machine operation (machine runnability and efficiency). The second important objective is to guarantee in the manufactured paper the quality specifications his customers are demanding.

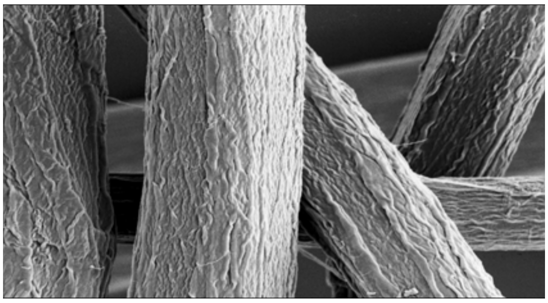
Since fibrous raw material performance behavior is difficult to be measured or predicted, the paper mill manager requests the help from the laboratory chief to perform what I call the **"management of peripherical pulp quality specifications".** He needs a number of selected data to help him to justify the problems he may eventually have when the machine runnability is poor, or the paper quality specifications are not being reached. When an uniform pulp intake is guaranteed; refining, chemical additions, sheet drainability, energy and steam consumption, web consolidation, and paper strength/physical properties do not sharply change and the paper process runs smoothly. The process and product qualities are more easily achieved. In an attempt to control some of these pulp quality parameters, the laboratory evaluates pulp brightness, brightness reversion, pulp cleanliness, pulp viscosity, pulp conductivity, pitch content, and performs some beating runs. The first and important goal is not to have sharp variations in the general pulp properties. Brightness, brightness reversion, viscosity, cleanliness, ash and mineral contents, and beating performance are the key issues in these "peripherical quality specifications. The complementary pulp quality parameter is the moisture content. The papermaker does not want to pay more to the pulp he is buying than what he considers to be fair and right.

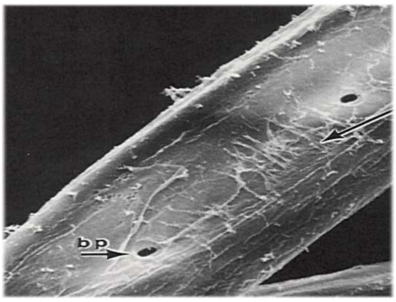
The second type of management that the mill manager wishes is the variability control. The **"management of pulp variability"** tries to guarantee a narrow variability in the pulp and its consequences. The variability is also measured indirectly, by watching the paper-machine behavior and performance. When machine works smoothly, without breaks, at pre-settled speeds, and the quality specifications in the final product are met, the process is said to be controlled, and variability has been tamed. When problems start to happen, the usually first accused is the pulp quality.

Management of peripherical quality and management of pulp variability are really basic physiological requirements in any paper mill. The mill manager needs to have these exigencies fulfilled to go further in the next type of management: the **"management for product differentiation"**, or **"tailor making orientation in the manufacture of products"**. This type of management requires substantial changes and offers important challenges to the paper mill personnel. The changes may happen in pulp quality (for example: long fibers and short fibers blends), pulping process conditions (for example: ECF or ECF-Light bleaching sequences reflecting on AOX and/or OX pulp contents), or even others recently added qualities (certified or non-certified wood in the pulp). Differentiation of paper products is more easily achieved in mills with more than one paper-machine. This means that the mill may run each machine with a differentiated product, without experiencing the usual troubles with transitions from one product to another using a single paper-machine. Anyhow, the tailor making concept will only be winner when the paper maker has guaranteed the two first mentioned types of management: peripherical pulp quality specifications and variability plus machine performance. It is very simple to say, but very difficult to understand and to implement. For this reason, many conflicts and misunderstandings are frequent among the commercial, production and product innovation areas in a paper mill. Each of these areas has its own needs and dreams about product uniformity, product uniqueness, and product differentiation. In most of the cases, each area has difficulties to understand the other side's position. As a result, few paper mills have products that may be said completely differentiated in their products portfolio. Most of the paper manufacturers aim to have a single product, as uniform as possible, with the minimum cost and maximum in productivity and in operational efficiency. Having in mind that the behaviors, needs, commitments and purposes are different, what is really important to promote a culture for tailor making in paper manufacturing? What is important to be managed? How to do this? What properties in the pulpwood may be successfully controlled to offer differentiation in paper products? What are the most important pulp parameters that the mill manager should care about? And the commercial director? What about the R&D manager?

In integrated paper mills, the paper product differentiation may be built at the forest, at the pulping process and/or at the paper machine. At the forest, it means to segregate the different wood and to cook the different types separately (for example: high and low wood basic density). At the pulp mill, the differentiation may be achieved taking advantage of the different opportunities the company may have (different bleaching lines, different digesters). Finally, at the paper mill, the different products may be also obtained by different pulp furnishes, involving blends of different pulps (produced onsite or purchased). In integrated paper mills, it is very common the need to purchase some dried pulp in the market, to facilitate drainage in the wet end. Dried pulps have much better drainage than never dried pulps, because they have substantially lower Water Retention Values. This offers a good opportunity for fiber blends and to improve the product portfolio.

In case the company may eventually have difficulties to handle different types of woods coming from forest areas that are not very close, one recommended solution is to work with a single, flexible and uniform wood supply, and to differentiate pulps and/or papers in the mill, not in the forest. This is the case of the well-known Fiber Platform, developed by Aracruz Celulose, in Brazil. Aracruz has a very good forest breeding program. However, the pulp company has increased wood consumption to an enormous level, due to the modernization and added capacity in the pulp lines. The company was used to grow forests in a workable distance for wood differentiation (about 50 to 70 km from mill). However, the extra demand of wood for supplying the huge new capacities forced eucalyptus forests to be planted in a ray of 300 km from mill, or even more. Considering that there is a very important interaction between genotypes and environments, the genetic material that is proved to be good in one region site does not perform as well in another region. The consequence: Aracruz has developed what is called “a high quality fiber platform”. The objective is to select and to develop trees with a broad wood and fiber characteristics and relative concentration on wood components (lignin and hemicelluloses). These trees should be able to provide optimum combination of pulp and paper properties (beyond pulp yield) according to different market segment demands. The wood is improved to provide better pulping attributes. The uniformity and flexibility on wood supply is reached by controlling genetics, species, age, silvicultural practices and forest environments. At the pulp mills, utilizing the different fiberlines the company has, the differentiation is defined to supply targeted markets and customers.





Kraft pulp fiber surfaces

It is relatively difficult to say what is the single most important pulp characteristic for a given paper mill. The reason is that there is not an universal pulp property to be managed. Depending on the paper mill bottleneck, the pulp quality is defined to guarantee the maximum performance to this mill. The most common bottlenecks are: refining capacity, drainage and retention in the wire section, paper-machine speed, steam availability, wet web consolidation and strengths, final product uniformity. As a conclusion, it may be said that the type of mill bottlenecks will define the most desirable pulp quality, up to a certain extent. This is the case for existing mills. For new greenfiend mills, the quality may be previously built and designed, before the construction of the paper-machine and auxiliary equipment's. However, soon the mill starts up, the bottlenecks will appear to define the new pulp quality standards. This is the reality, no doubt about. This is also the cause for domestic conflicts within the company.

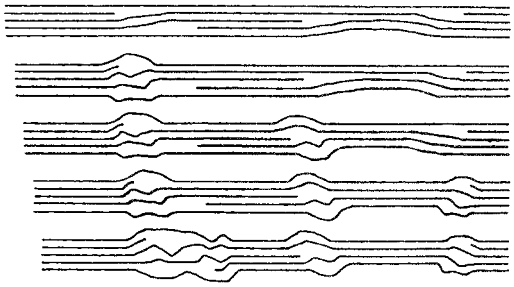
EUCALYPTUS PULP AND FIBER QUALITY REQUIREMENTS FOR THE PRODUCTION OF PAPER

Paper mills have targets for productivity, quality, costs and efficiency. Eucalyptus pulps are raw materials for the manufacture of several grades of papers. For each paper grade and for each paper mill design, different may become the pulp quality requirements. This means that there is not an universal pulp, a pulp that may perform well everywhere.

Wonderful & magic eucalyptus short-fiber pulp

Productivity means fast speed in the paper machine, fast drainage in the wet end, high consistency after wet presses, excellent consolidation in the paper web, and minimum number of paper sheet breaks along the machine. Quality implies in maximum percentage of paper in the specification ranges and minimum generation of broke. Machine operation efficiency is the dream of any paper manufacturer. He wants his machine working smoothly, at the maximum speed as possible, no breaks, no maintenance problems, and achieving the required quality in the manufactured products. The consequence of all this is that the specific unit cost is also here optimized. No doubts that a good pulp is the one able to provide good paper-machine runnability and appropriate quality in the end product, no matter this paper product is a commodity (toilet tissue, cut size paper, etc) or a specialty grade (industrial filters, cigarette paper, etc).

Some of the pulp properties are very much related to these performances. For this reason, the papermaker should keep an eye on them. Some of these properties are result of the wood quality, other depends on the conversion of wood to pulp (chipping, cooking, bleaching, pumping, blending, etc), and many are a combination of these two factors influencing the pulp quality. For example, some properties that are related to pulping and bleaching are: viscosity and degradation of cellulose chains, fiber deformations, cell wall integrity, individual fiber strengths, surface charges in fibers, adsorbed ions on pulp surfaces, etc. Some other important pulp properties are related to wood quality and pulp conversion, as the hemicellulose content in the pulp and the microfibril organization in cell wall. The hemicellulose content depends on how high is the presence of hemicelluloses in the wood and in the ability of the pulping and bleaching processes to preserve them in the pulp fibers. The organization and integrity of the microfibrils in the cell wall depend on how aggressive the pulping process has been to the original fiber wall, and also the type of original wall in the wood (reaction wood, juvenile wood, etc).

Organization of the microfibrils and pores in the fiber wall structure after pulping operations

There are other properties that are 100% dependent on the wood supply, the pulping and papermaking processes cannot modify them: fiber length, fiber wall thickness, vessel dimensions, etc.

There are many pulp properties that are dependent both on wood quality and on pulping/bleaching processes. There are also many cases where many exigencies are placed on the wood quality, when the wood is not the main factor to determine these pulp qualities for paper. It is the case of properties as: WRV – water retention value, WWS – wet web strength, WFF - wet fiber flexibility, fiber bonding and individual fiber strength. There are many other properties related not only to the wood quality. For example, the fine content of the pulp. Fines in the wood are mainly parenchyma cells, but in the pulp they are also fiber and vessel fragments that are generated in operations such as wood chipping, pulp pumping, pulp dynamic mixing, pulp pressing for dewatering, etc.

<u>Back to the papermaker</u>:

As a rule, there are some physiological requirements that any pulp has to fulfill to be loved by papermakers. They are related to the following needs:

<u>Physiological need number 01</u>: *Drainage and retention in the wet end section in the paper-machine*

This behavior is very much affected by the fiber population (number of fibers per gram of pulp), by the initial or refined pulp freeness (drainability of the pulp measured as Canadian Standard Freeness or Schopper Riegler degree), by the Water Retention Value (hydration and swelling ability of the pulp furnish), by wet fiber flexibility and ability to form and to consolidate the web and by the fines content in the pulp furnish. The wire/fabrics design and cleanliness, many times forgotten as process quality parameters, are also very important to the fulfillment of this physiological need.

Physiological need number 02: *Paper sheet strength along the paper-machine, mainly at the wet end and press section*

This sheet behavior is very much dependent on the individual fiber strength, fiber length, fiber bonding, furnish contaminants (shives, sand, solid debris, etc), and on the consolidation potential of the paper web. Individual fiber strength is related to fiber wall thickness, fibril angle, fiber deformations and micro-fractures, and to the *Eucalyptus* species.

Physiological need number 03: *Achievements of final paper specifications as requested by customers (or by the quality control laboratory!)*

According to the paper we are manufacturing, the demands on specifications (fibers and pulps) are different. Sometimes, these differences varies for the same grade of paper, but being manufactured in different paper-machines. Each individual process may have some particularities that lead to different pulp needs and operational conditions.

As far as the physiological needs are achieved, the papermaker feels enthusiasm to work for differentiation of products. Differentiation implies in different products to be supplied to different markets or customers. One of the most important ways to reach differentiated products is through the control of the eucalyptus pulp and fiber quality. The genetic improvements on the wood quality may, not only help to reach the physiological needs in the pulp and paper manufacturing, but also to provide very different pulp fibers to be supplied to the manufacture of different products. This is what is known as to tailor making the wood to the end product.

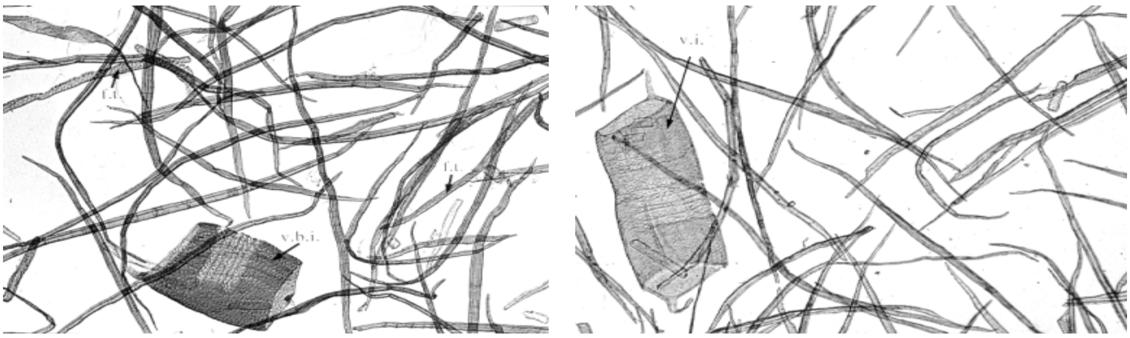
However, genetics, silviculture and wood quality are not the sole responsible for the pulp behavior. The pulp performance may have its foundations at the forest, but this is not all. We have seen that pulping and papermaking processes may contribute a lot in changing the pulp qualities and behaviors. What we definitively need to know are the existing relationships and how to take control of them.

THE MOST IMPORTANT EUCALYPTUS PULP AND FIBER PROPERTIES

Today, the pulp and paper laboratories are squeezed by thousands of different types of analyses. Some mills are spending so much time on measuring everything, that the speed to take decisions and actions is completely affected. The laboratory manager has fewer people, due to the constant downsizing obliged by the company's high administration. He feels lost, but he wants to keep his area working as much as possible to satisfy his customers (paper production manager and commercial manager). Since the number and the type of analyses grow due to the Information Technology support, the time to reflect over the results decreases. The danger is that the quality of the data may also be affected.

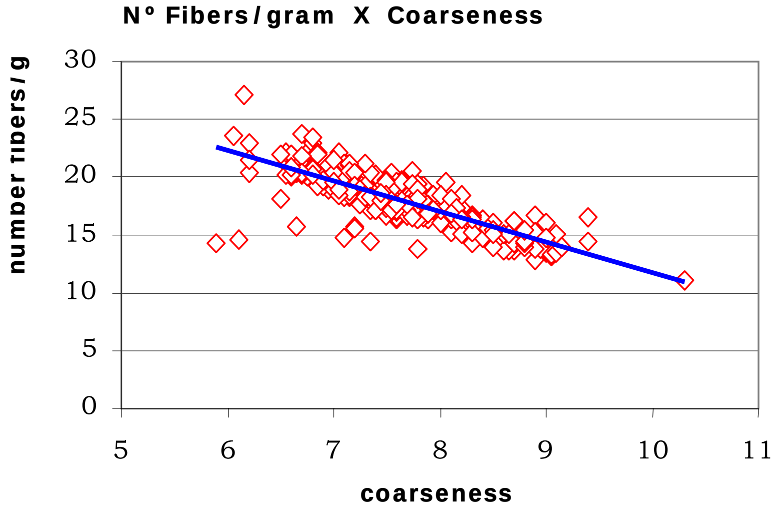
The following pulp quality parameters are key drivers to distinguish the different eucalyptus fibrous raw materials and to allow pulp furnish optimizations:

- **Fiber population or the number of fibers per gram of pulp (associated to fiber coarseness)**



Source: Portucel/Soporcel, 2003

The fiber population is related to the weight of each individual fiber, and by extension to the fiber coarseness and to the percentage of fiber wall in the fiber volume. Fiber population is a compound property derived from fiber length, and fiber coarseness. Since fiber length in eucalyptus pulps is a morphological property relatively stable (the weighted average ranges from 0.6 to 0.85 mm maximum), there is a strong correlation between fiber population (Number of fibers/gram) and fiber coarseness.



Source: Milanez, 2007

There is a number of fiber properties associated to fiber population and fiber coarseness: fiber length, cell wall thickness, cell wall cross sectional area, fiber wall fraction (ratio between cell wall thickness and fiber ray), Runkel index, fiber flexibility index (ratio between the lumen diameter and fiber diameter), fiber collapsibility, ratio fiber wall thickness and fiber perimeter, cell wall packing density, wood basic density, wet fiber flexibility, and fines content.

Since fiber population and fiber coarseness are definitively some of the most important eucalyptus pulp properties, it is very important to know the type of effects they may impart to papers.

First, it is important to understand the fiber morphological characteristics related to fiber population:

- Cell wall thickness (-)
- Fiber length (-)
- Cell wall fraction (-)
- Cell wall cross sectional area (-)

It is clear, that the relationships of these above mentioned morphological characteristics with fiber coarseness are in the opposite way. It is relative simple to understand that higher coarseness in eucalyptus fibers are associated with thicker walled fibers. These fibers produce a more open and loosen paper structure. Fibers are rigid and difficult to be collapsed. Fiber bonding and fiber consolidation are not that favored with such stiff cylindrical fibers. The corresponding papers are more porous, bulkier, and more absorbent.

A better consolidation of the paper web is expected with more fibers per gram in the paper structure. As a result, higher the fiber population better is the inter-linkage among fibers, and better are the properties depending on bonding (tensile, folding, surface strength, surface smooth). Paper formation also pleases high fiber population in the furnish. The number of fiber to fiber crossings in the web at a constant paper grammage and sheet area is expected to be proportional to the fiber population. Because bonding is favored, the paper properties that do not like fiber bonding are affected negatively (bulk, porosity, water absorbency, tactile sensibility or softness, surface roughness).

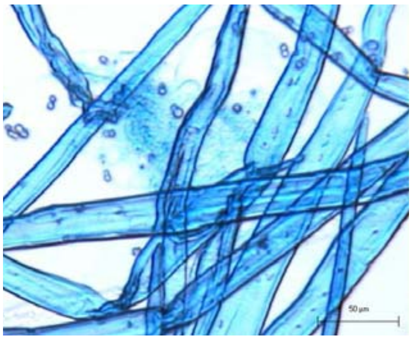
Coarseness in eucalyptus fibers varies from 4.5 to 11 mg/100m. Fiber population, in opposition, varies from 12 to 30 million of fibers per gram of pulp. Both properties have wide ranges of variability, and allow good selections of pulps in the market, depending on the desired end-use.

Fiber population and fiber coarseness are associated to a great number of paper properties. To simplify things, let's inform the correlation of fiber population with some of the most important paper properties, no matter the type of paper. Obviously, the correlations for fiber coarseness will happen in the opposite way.

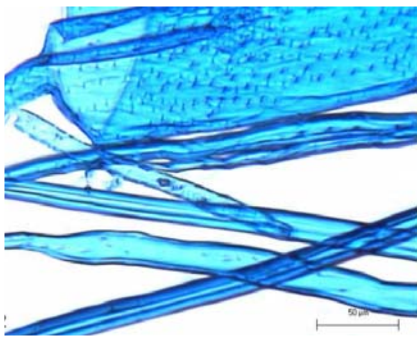
Fiber population correlates positively with: formation, surface smoothness, opacity, light scattering coefficient, fiber bonding, surface strength, tensile strength, burst strength, folding, air resistance, water retention value, wet fiber flexibility, wet web strength, wet web stretch, unbeaten Schopper Riegler.

Fiber population correlates negatively with: porosity, stiffness, drainage, bulk, tear strength, dimensional stability, water absorbency, paper softness.

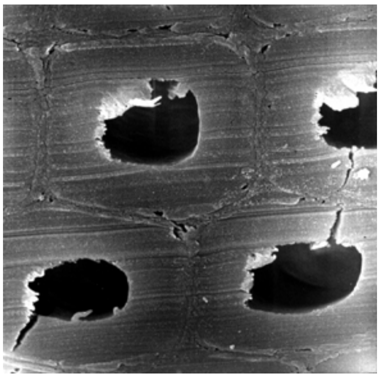
It may be also shortly said that pulps with lower fiber population show better drainage in the wet end, and the paper sheets are more porous, bulkier, more permeable and absorbent. They are very much appreciated by papermakers because they allow faster machine speeds, as far as the furnish may impart enough strengths to the wet paper sheet.



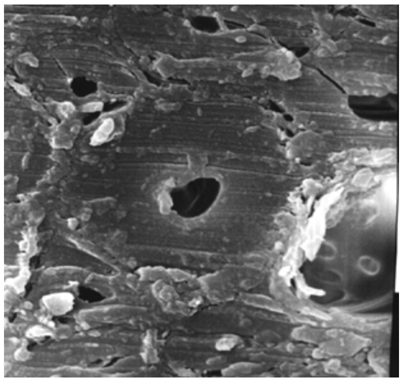
Low coarseness and low wall fraction fibers
Source: Queiroz, 2002



High coarseness and high wall fraction fibers
Source: Queiroz, 2002

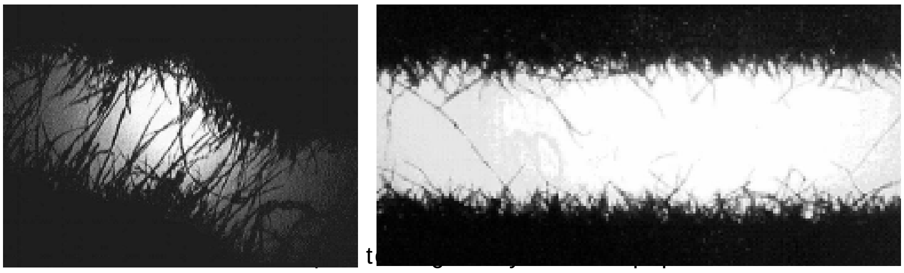


Low coarseness and low wall fraction fibers
Source: Milanez, 2007



High coarseness and high wall fraction fibers
Source: Milanez, 2007

- <u>**Individual fiber strength**</u>

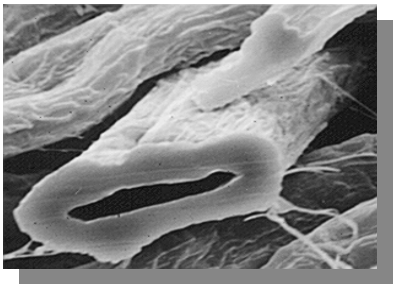
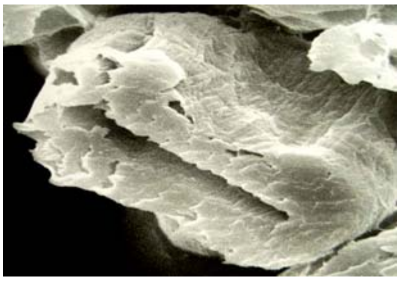
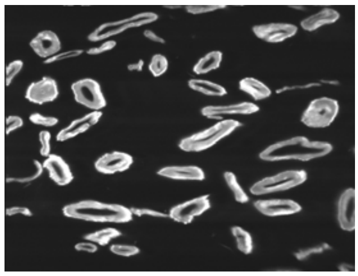


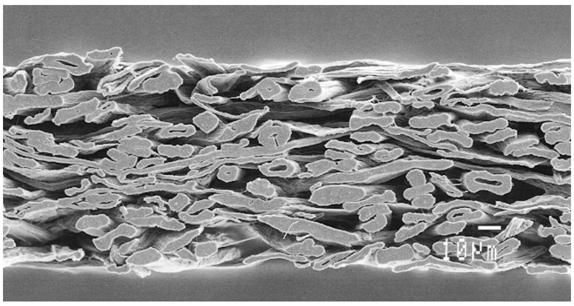
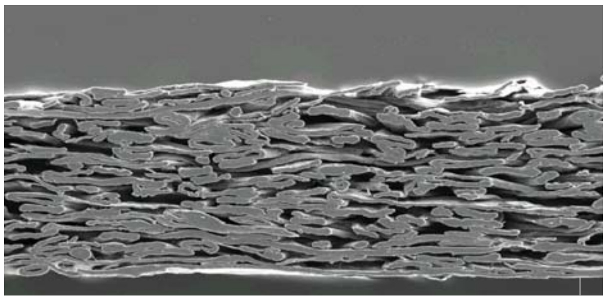
This fiber characteristic is very difficult to be measured in short fibers as those from eucalyptus. There are tests correlated to this strength, as the zero span, very useful for predicting pulp quality and behavior previously to send the furnish to the pulp-machines. Fiber deformations (curl and kinks), micro-fractures in the cell wall, and other fiber defects may contribute to reduction on the individual fiber strength. The consequence of reduced individual fiber strength may be reduced WWS (wet web strength) and dry paper strength properties.

Zero span tests provide good indications on the fiber wall resistance. There are different parameters that the zero span test may evaluate: wet zero span, dry zero span, wet short span, dry short span, B value. These tests provide sound and valuable correlation with fiber specific strength and also with fiber bonding ability (B value). Zero span most valuable tests related to individual fiber strength are the wet and dry zero span. These results are affected by: fiber wall integrity (+), cell wall packing density (+), fiber length (+), pulp viscosity (+) or cellulose chain degradation (-), micellar angle (-), hysteresis (+), fiber wall fraction (+), and fiber chemical composition. Although many times referred as an excellent indicator to individual fiber strength in softwood pulps, the micellar angle does apparently not play so important role for eucalyptus pulps. Most of the eucalyptus fibers have small angles, relatively close to the fiber axis. In the S_2 layer, this angle has been found ranging from 8 to 15º.

The intrinsic strength of the fiber may be given either by the dry zero span and/or the wet zero span. For eucalyptus pulps, in unbeaten level, the ranges of results are the following: Wet Zero Span (from 70 to 140 Nm/g) ; Dry Zero Span (from 90 to 160 Nm/g). B Value is related to increased fiber bonding in the fibrous test pad. Higher the value, better the bonding (results for eucalyptus pulps varies from 1.5 to 3).

- **Fiber collapsibility**

Fiber collapsibility is associated to the wet paper sheet compactability. Wet sheet compactability is referred to the readiness the fiber surfaces are adapted and conformed to each other when the wet sheet is pressed. A well conformed wet sheet has more ability to keep fibers and fillers together and conformed after paper drying. The sheet compactability makes the paper sheet denser and places the fiber walls closer to each other during paper manufacturing. As a consequence, fiber bonding is sharply improved, and the strength properties depending on bonding (tensile, burst, folding, surface strength) have their results raised. On the other hand, some very welcome eucalyptus pulp properties are lost: bulk, porosity, opacity, water absorption, softness, dimensional stability. Fiber collapsibility and wet sheet compactability are result of the fiber resistance to collapse. There are other chances for collapsing fibers in a paper mill, as the operations of paper drying and paper calendering. However, the wet paper compactability has more effect on collapsing the fiber wall. Collapses convert cylindrical fibers into flat ribbon-like fibers, with better link and contact surface. The lumen collapses because the fiber structure (cell wall and fiber architecture) is unable to support or to absorb the energy applied by the papermaking pressures and forces. In most of the cases, the thick-walled fibers, with higher fiber wall fraction, are stiff, rigid, and more resistant to collapse. Eucalyptus fiber collapsibility is also negatively related to fiber coarseness. Higher the fiber coarseness, lower is the ability of the eucalyptus fibers for collapsing. The fibers with greater potential for collapsing are usually more difficult to drain the water in the wet end of the paper-machine.

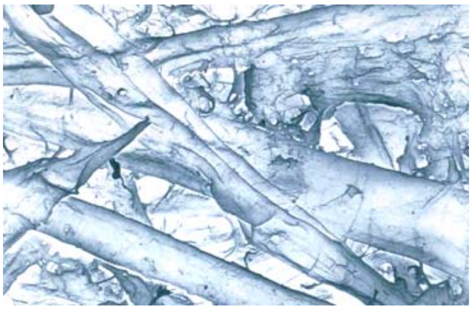
Another morphological property very much related to fiber lumen collapse is the cell wall cross section area (area of cell wall in the fiber cross section or diameter). A derived morphological characteristic is the cell wall density or packing density. It is calculated based on the fiber coarseness and the cell wall cross sectional area. The formula for this calculation is:

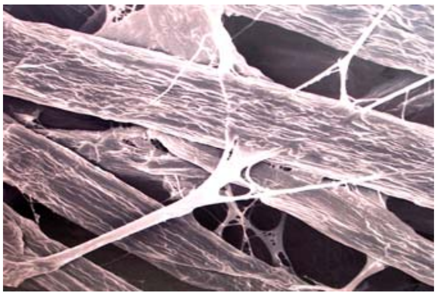
Cell wall density (g/cm^3) = (10 x coarseness) / (wall cross sectional area)
Coarseness in mg/100m
Cell wall cross sectional area in micrometers

One indirect measure of fiber collapsibility is the dry paper sheet bulk (or sheet density) at a given Schopper Riegler or freeness level, or at a given tensile strength. Higher the bulk in a certain level of drainability or tensile, more resistant are the fibers to be collapsed. Higher the density of the sheet, more collapsed are the fibers, and more compacted the paper sheet. Bulk or sheet density at a given drainability (for example 25 or 30ºSR) or tensile (for example 50 to 70 Nm/g) and fiber coarseness, are able to give good indications of pulp behavior in relation to fiber collapsibility.

Another interesting property to be measured at a given freeness (or at a given bulk, or at a given tensile) and strongly related to fiber collapsibility and paper compactability is the dry paper porosity (or the opposite property, the air resistance).

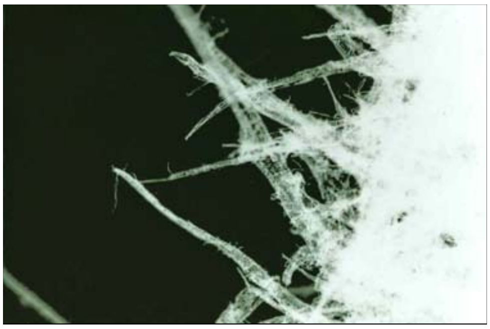
- **Fiber bonding ability and paper network properties**



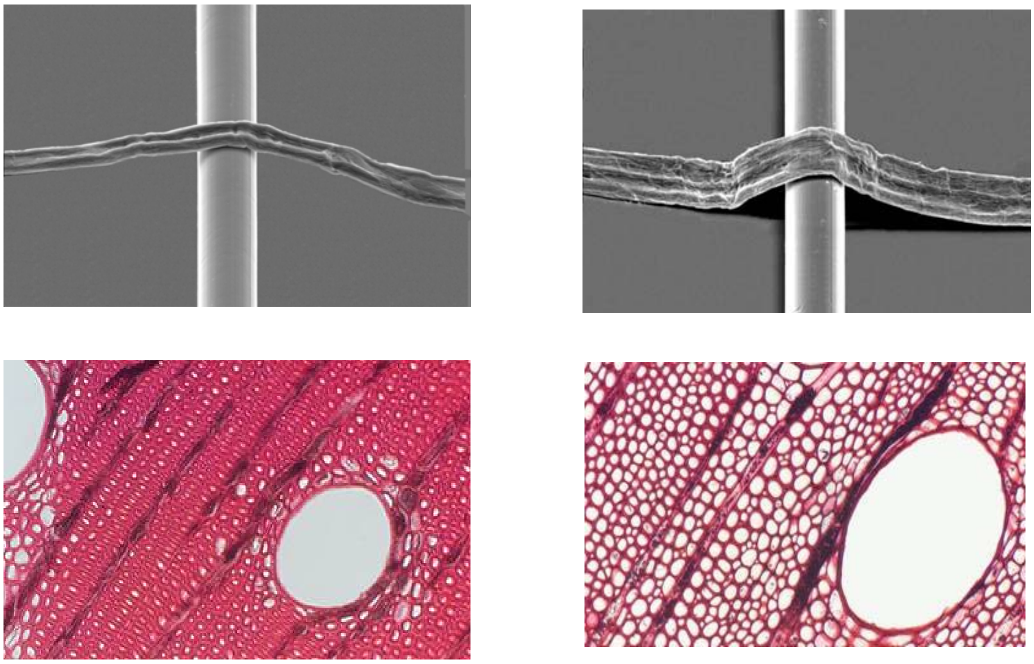


Bonding of fibers: very important in paper manufacturing process

Better the fiber bonding, better is the paper sheet cohesiveness. Cohesiveness and bonding are developed by beating (fibrillation and fiber collapsibility) and by the presence of fines and fiber debris. Bonding may be measured by the dry/wet short span (B value) technique or by other equipment for dry paper bonding tests, as the Scott bond tester or wax picking of paper surface. Bonding is also related to a number of dry paper strengths, as tensile, burst, folding, and also to sheet apparent density. It is also related to the hemicellulose content of fibers, fiber population, fiber drainability (CSF or ºSR), fines content and fiber collapsibility. Bonding is very much related to pulp fines content and web consolidation by pressing and collapsing fibrous materials. Higher is the sheet density, the more bonded are the fibers and other anatomical and chemical elements present in the paper structure. Low hemicellulose content and high coarseness fibers reflect in low cohesiveness and low bonding. Instead of being "glued or linked" to each others, these types of fibers are rigid and stiff: "they tend to touch and to stick one to another, but they are not glued". Finer fibers with lower coarseness values and higher fiber population make closer-formed and better printing oriented sheets of paper.



- **Wet fiber flexibility**

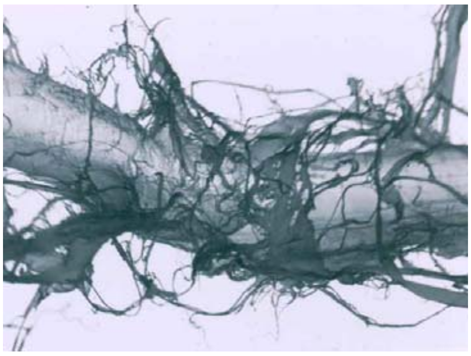


Wet fiber flexibility test on high coarseness (left) and low coarseness (right) eucalyptus fibers
(R. Steadman & P. Luner methodology)
Photo courtesy: Aracruz Celulose - Ergilio Claudio-da-Silva Jr & Braz Demuner

Wet fiber flexibility (WFF) is one of the most important pulp properties. It is highly related with inter-fiber bonding (+), fiber lumen collapsing (+), water retention value (+), and bulk (**-**). It has been proved for several researchers that wet fiber flexibility is easily measured and gives a very good indication of paper strengths and paper optical properties. The wet fiber flexibility correlates very well with the paper conformability, paper consolidation, and fiber collapsibility. However, WFF is affected by fiber deformations and cell wall damages. WFF is the opposite property when compared to fiber stiffness. As a measure of flexibility, the condition is that a force be applied to bend the fiber in its length. What is really very important to papermaking is that WFF correlates very well with Wet Web Strength and Wet Web Stretch, two very important properties for predicting machine runnability.

Wet fiber flexibility shows very good correlation with several fiber characteristics, as follows: fiber coarseness (**-**), cell wall thickness or cell wall fraction (**-**), paper tensile strength (+), paper sheet density (+), Water Retention Value (+), fiber stiffness (**-**), paper sheet bulk (**-**).

- **Fiber swelling and hydration**



Fiber wall delaminating & fibrillation process and hydration at refining

This property is very affected by the pulping and bleaching operations during pulp manufacture, and by the pulp hemicellulose content. Several properties are associated to the swelling of fibers: freeness or Schopper Riegler level, WRV - Water Retention Value, fiber charges, carboxyl groups, fines, fiber wall micro-porosity, fiber wall micro-fractures, wet fiber flexibility.

Hydration of fibers has to be understood under different approaches. First, we have the cell wall water, the water that is absorbed to the fiber wall due to fiber charges and polarity (carboxylic groups, carbonyl groups, etc) and micro-porosity. Second, we have the water retained by capillarity inside the lumens. More lumen volume a pulp has, more water will be retained in such way. Third, we have the inter-fiber water, the water that stays held between the fibers in the pulp mat.

Water Retention Value is a measure of the affinity of the pulp for water. Depending on the fiber network, and on the number of fibers/gram, more or less water will be retained by the pulp. When Water Retention Value is measured utilizing a pulp pad and a centrifuge to perform the test, the resulting WRV gives a number comprising all these three types of water. It is easy to understand that pulps with fibers containing more lumen total volume, and more fibers have higher WRV results. Small pores (lumens) are able to hold water more strongly than large pores due to the greater surface tension forces associated with the small pores. As a consequence, WRV is strongly related to fiber population (+), fiber coarseness (-), cell wall fraction (-), wet fiber flexibility (+) and fiber saturation point (+). WRV is also influenced by the chemical composition of the fibers. The hemicelluloses retains more water, thus, fibers with more hemicelluloses are able to retain more water in the fiber walls. On the other hand, most of the pulp extractives are hydrophobic. Pulps with high extractive content have poorer ability to retain water in the fiber wall.

It should be well understood that WRV is a combined effect of chemistry (hemicellulose content) and physics (fiber population, total pore volume and pore size distribution). This combined effect will be responsible for the WRV result. You may eventually have a pulp with low hemicellulose content, but with high WRV due to a huge fiber population.

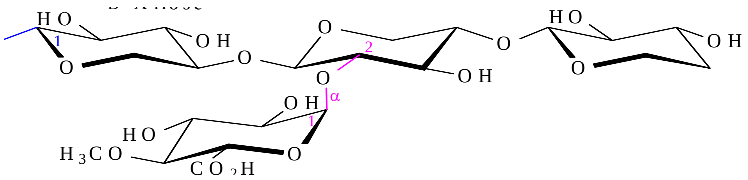
The high hemicellulose content associated with high fiber population and degraded fibers (low viscosity) will lead to pulps very hard to drain in the paper machine. These unbeaten pulps have high initial Schopper Riegler degree, proving that drainability is difficult even in the measurement of this property. Paper machine runnability is negatively affected in these conditions. There are eucalyptus pulps with high hemicellulose contents, as example the *Eucalyptus globulus* market pulps. However, a typical feature of *E.globulus* is the high fiber coarseness, and low fiber population. Under these circumstances, the WRV in *Eucalyptus globulus* pulps does not represent problem in normal conditions.

To the papermaker, mainly the one manufacturing porous and absorbent papers, <u>the porosity and capillarity he is concerned are those in the paper sheet</u>. High WRV pulps may have a huge small pore volume (lumens) in the pulp pad used for testing WRV, but these pulps are not recommended to the manufacture of tissue and filter paper. The reason is understandable. These pulps have high WFF, high population of fibers, thin cell walls, high ability to have the lumens collapsed. The paper structure will be dense and compacted, unless the papermaker may have some magic procedure in the manufacture.

Excessive fiber swelling and hydration may be a problem in integrated mills, when the pulp has never been dried prior to its use in paper manufacturing. When a pulp is dried, the hysteresis phenomenon provides a substantial reduction in the WRV of the pulp. Dried pulps, with lower WRV, have a much better drainage in the wet end. However, they are somewhat more difficult to be refined, but the desired strengths are reached in a drainability level that is still convenient to the machine operation. For this reason, in many occasions in an integrated paper mill, the mill manager loves to add some broke (already dried fibers) to the furnish. He believes that some broke is required to improve the performance of the furnish. It is a completely inappropriate thinking, since broke recycling is a loop in his process: he is wasting all the value has being added to the manufacture of this paper. Even worse, he is reducing the paper-machine net production. The machine has part of its capacity filled by a recycled material, in a loop that consumes resources, reduces capacity and raises costs and inefficiency. In case an integrated mill may eventually have problems due to excessive furnish swelling caused by any reason, the most simple method to improve machine runnability is to buy or to add some dried market pulp in the furnish recipe. The pulp drying operation causes substantial reductions in the WRV and WFF, favoring wet end drainage. However, dried pulps are more difficult to be refined and to develop pulp strengths.

Today, there is a trend among pulp buyers to request higher market pulp pH in the pulp sheets. This trend is happening due to alkaline sizing in printing and writing paper manufacture. The papermaker wants to save some money in chemicals for controlling pulp furnish pH and pulp refining. Higher pulp pH means more swelling in the pulp, and more difficulties to drain the pulp sheet in the wet end of the pulp drying machine. The usual market pulp pH has been 5.0 to 5.5 for years. Today, to many customers, the trend has been raising it to 7.0 – 7.5.

- **Hemicellulose content of the pulp**



Hemicellulose content is vital for papermaking. Pulp makers also love to preserve hemicelluloses in the digesting and bleaching operations. They are improving the pulp yield, and consequently, reducing costs and raising economic margins. Pulps with low hemicellulose content, as the dissolving pulps, are hardly beaten, and fiber bonds are weaker and fewer. Since the great percentage of the eucalyptus pulp hemicelluloses are xylans, the significance of the pentosan content to predict pulp quality is very important. Those pulps containing more hemicelluloses are able to produce paper with better fiber bonding, better strengths properties, better surface smoothness, and lower bulk and porosity. No other fiber chemical component in eucalyptus bleached kraft pulps has so much influence on paper properties than the hemicelluloses, provided these pulps have not been damaged or degraded too much in their manufacture.

The hemicellulose content in pulps can be affected by the today's operation of the modern digesters. The type and operation of the bleaching sequence is also responsible for removing more or less hemicelluloses. These two factors combined may represented significant improvements or losses in the pulp manufacturing stage. Consequently, the pulp manufacturer must understand very well its role in this process. The wood raw material, the pulping and bleaching operations, and the pulp mill daily performance may represent opportunities to save or to reduce the hemicellulose content in the pulp.

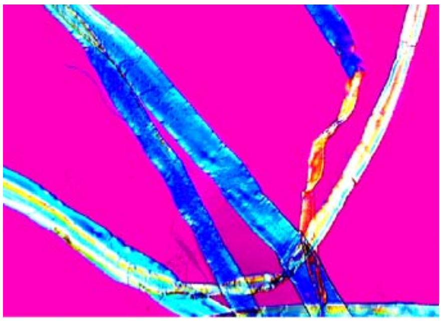
Hemicelluloses are very hydrophilic organic compounds. The presence of high hemicellulose content in the pulp helps to increase the ability of the fibers to attract and to retain water in the fiber wall. This phenomenon improves the fiber swelling, brings weakening in the microfibril linkages in the cell wall, and favors the pulp refining. Higher the hemicellulose content, better is the wet fiber flexibility, and improved becomes the fiber bonding. Fiber walls may become more plastic and flexible. As a consequence, for the same level of fiber coarseness and pulp refining, the pulps containing more hemicelluloses give origin to denser paper sheets, and sheets more resistant to the flow of air in the paper Z direction (reduced porosity). Sheet softness is also negatively affected. Although the hemicelluloses are hydrophilic compounds ("friends of the water"), when they cooperate to reduce paper sheet bulk due to collapsed fibers and better bonding, the paper sheet become less porous. The reduced porosity of the paper structure has lower ability to absorb and to retain water. Curious behavior, intriguing performance: chemically speaking is favorable, but physically may not.

Because the characteristics the hemicelluloses impart to the pulps, there are a number of other papermaking performance items being affected. Drainage in the pulp machine may be negatively affected, but there are cases of opposite behavior. This happens when the pulp refining may be driven to lower Schopper Riegler levels to achieve the same required strengths. In these cases, the machine runnability does not suffer. When the refining is performed to a lower level of ºSR, there are very good improvements in the machine runnability and paper properties: drainage, steam saving, paper dimensional stability, softness, porosity, etc.

For some grades of papers, the effects of hemicelluloses are not completely welcome: tissue, decor, impregnating-base papers, etc. The removal of hemicelluloses may become a solution. This "removal" may be achieved in several ways: utilization of low hemicellulose content wood raw material; more intense cooking to lower kappa number and with more alkalinity in the end of cooking to prevent xylan re-precipitation; removal of hemicellulose by drastic alkaline bleaching stage. When hemicelluloses are partly removed, the weight of each individual fiber is reduced in some extent: this means that the number of fibers per gram of pulp is increased, and coarseness reduced. The reduction on hemicelluloses in the digester is painful to the pulp maker. The pulp yield drops considerably in this operation. Drastic pulping of wood helps to reduce hemicelluloses to more acceptable levels for tissue manufacturing, but pulp yield may drop about 1.5 to 2.5% based on wood. This means more wood cost in the pulp cost; or reduction on pulp production in case the digester, the causticising or the recovery boiler are bottlenecked in the pulp mill. As an indication of effects: a reduction of 2.5% on the bleached kraft pulp hemicellulose content allows reductions of 10% in tensile strength, and improvements in bulk, porosity and absorption.

In recent days, new opportunities to remove hemicelluloses from wood, and associated to pulp making, are been investigated. The concept of bio-refinery is exactly proposing the utilization of part of the wood hemicelluloses to the manufacture of ethanol, a valuable biofuel. The consequence will be interesting: the possibility to differentiate eucalyptus pulps reducing hemicellulose content without bringing damage to the pulping process or to the environment (more COD in the bleaching filtrates, when hemicelluloses are removed in the bleaching line).

- **Fiber deformations and cell wall integrity/damages**



Curl and kinks in fibers (Source: Paprican, Canada)

Eucalyptus pulp fibers are submitted to very hard mechanical forces and stresses. Fiber life is not really easy, believe me. During cooking and bleaching, the alkaline conditions along these processes favor the structural disorganization of the microfibril chains in the cell wall. The removal of wood constituents during pulping and bleaching creates macro-pores in the cell wall. The wall becomes more fragile and damaged in relation to its original organization in the wood. This cell wall fragility enables the fibers to suffer more and to deform when mechanical forces are applied to them. Deformations and lumen collapse become more frequent. More the fiber is damaged during pulping and bleaching, more sensitive is the fiber wall to be deformed and collapsed.

The alkalinity favors fiber hydration and wall swelling, it helps to loose the microfibrils in the wall structure. The fibril network becomes loosen and more porous. This helps pulp refining and improves fiber bonding and wet fiber flexibility. However, the individual fiber strength is reduced. Severe cooking conditions to reduce kappa numbers or to delignify denser woods in general are very harmful to cell walls. At the same time, more hemicelluloses are removed from the fibers. The fibers become weak and sensitive to the mechanical forces, such as those created in presses, pumps, valves, agitators, etc. For these reasons, sometimes we have pulps with the same wall fraction and obtained from the same eucalyptus wood raw material, but with distinct fiber strength and paper performance. This may be explained by an excessive cooking or bleaching in one of them.

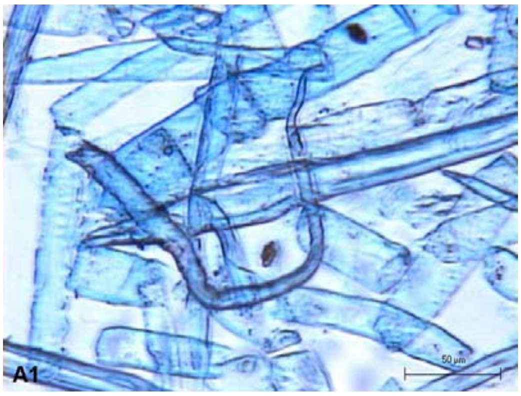
Degraded fibers have increased Water Retention Value and Fiber Saturation Point. They absorb water more easily because the microfibrils are more open, loosen and the fibril network more porous. Wet fiber flexibility is also increased, and together, the ability for lumen collapsing. These pulps have fast beating response, the Schopper Riegler degree raises fast. However, this is not followed by an increase in pulp strength (tensile and tear). Fibers are weak, they are more easily broken and form more fiber debris and fines. Wet Web Strength and Zero Span are also harmed. This is a terrible world, but it is a real world in many pulp mills. Degraded fibers like these do not behave as normal fibers. They are not able to resist the forces of the refining, wet pressing, etc. The papermaker faces a dilemma: “fast refining, high swelling, but no strengths, no bulk, no porosity”.

What shall pulp makers do to prevent fiber wall damages, and to preserve fiber wall? How to reduce carbohydrates peeling reaction? Professor Panu Tikka, from the Helsinki University of Technology, recently proposed: “Instead of thinking about residual lignin or residual hexenuronic acids in pulp making, better to think about the residual fiber”.

When fibers are submitted to mechanical forces, they are sensitive to changes in their form, no matter they are low or high viscosity. Deformations in good quality fibers are interesting for a number of reasons. The deformations in the fibers are measured as curl index, fiber kinks, fiber latency, and fiber micro-fractures in the cell wall. They affect the individual fiber strengths, but they provide substantial improvements in the paper sheet porosity, bulk, softness and water absorption. Fiber deformations are possible to be developed by artificial means at the pulp or the paper mills (shredders, washing presses, etc). Although not completely implemented as a source of pulp and paper differentiation, the utilization of fiber deformations for this particular subject may become more significant in the years to come. Mainly considering that pulp strengths are not the most demanded properties in the eucalyptus pulps. They are important, but not vital.

- **Fines content in the pulp**

Fines and fiber debris in an eucalyptus market pulp low consistency furnish
Photo courtesy: Techpap, CTP Grenoble and Regmed



Fines (parenchyma cells) in an eucalyptus pulp
Source: Queiroz, 2002

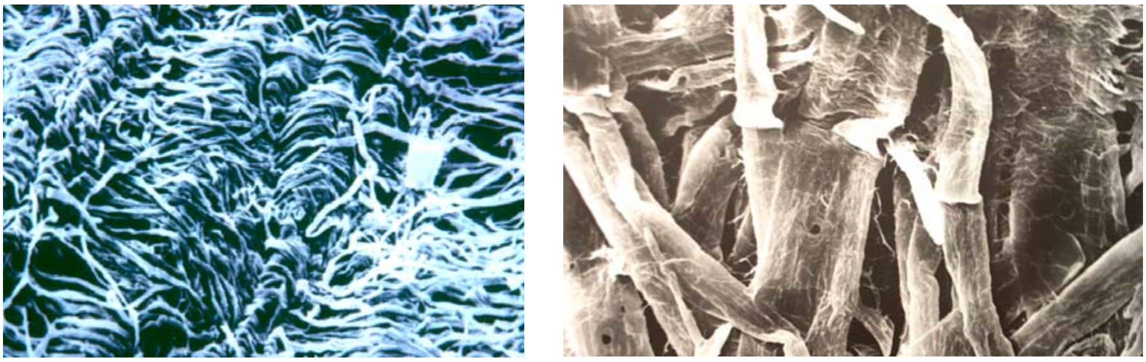
Fines are perhaps one of the most important kraft pulp properties, and most of the times, they are seen as a problem, never as a solution. This fundamental property is being neglected by pulp and papermakers, perhaps because fines are no fibers, they are debris or "weak parenchyma cells". Fines are seen as a filler in the pulp supply. They are created in great extent when the pulp is refined, what means that fines dramatically affect drainability in the wet end section. What I would like to propose to papermakers is really to pay attention to fines in the furnish. The best methodology to measure fines in a pulp stock is the dynamic jar test, developed by Dr. Britt. It is based on the percentage of the dry weight of a pulp that passes through a 200 mesh wire (openings of 70 micrometers), under constant conditions of time, temperature and consistency.

The "management of fines" in the furnish may provide to paper operators one the most simple and convenient methods to control the great majority of the end-product properties. When a paper mill has two or more machines, the management of fines, via the white waters, may be even more effective, by distributing fines in right dosages in one or another paper machine, according to the paper grade being manufactured. A low fines content eucalyptus pulp is able to better perform in the paper machine. Formation, softness, bulk, porosity, absorption, dimensional stability, and permeability are improved in the paper sheet. Strengths are reduced in opposition to these other gains. In terms of machine performance, the reduction on furnish fine content improves the drainage in the wet end, the consistency after wet presses, and the consumption of steam in the drying section. For this reason, fractioning of fines may become an operation to be considered according to the paper end-product being manufactured. In cases of machines bottlenecks, fractioning of fines may also become a solution.

THE MOST USUAL EUCALYPTUS PAPER PRODUCTS

In case we are good enough in providing the right furnishes to the paper manufacturer, he is able to add runnability to his machine and to go sleeping at home without any nightmare. However, according to the grades of paper he is manufacturing, he is demanded to have differentiated properties in the final product. Eucalyptus pulps are special products to the manufacture of bulky and/or opaque papers. Today, eucalyptus pulps are preferred raw materials in the manufacture of tissue, printing and writing, cartonboards, industrial filters, base-papers for impregnation or coating, cigarette and many other papers. Eucalyptus fibers may be the sole fiber in the pulp furnish or to be part of a blend with other short and/or long fibers.

- **Tissue and high bulk papers**



Tissue paper surfaces (loosened structure to improve absorption and softness)

Tissue (and other highly porous papers) demand the following quality requirements in relation to paper specifications and machine runnability:

- bulk
- loosened paper structure
- liquid absorption (fast absorption and capacity to retain water)
- hydrophilic paper surface
- porosity (pore sizes and distribution)
- structural softness (the feeling of a soft and fluff paper)
- superficial softness (tactile softness, the feeling when touching paper surface in the act of crumpling or wrinkling the tissue paper sheet)
- drawings caused by dry creping and embossing (these drawings improve the feeling of softness and provide better absorption and beauty to the paper sheet)
- exact paper strength (wet and dry) to allow not to fall apart when customer is utilizing the paper
- minimum tensile strength (it is said to be maximum 20 Nm/g in the furnish), to prevent fiber lumen collapse, excessive bonding and high paper density
- minimum elasticity modulus, a mechanical property negatively correlated with paper softness
- capacity in the paper to retain pulp anatomical components (fines and vessels) to avoid excessive dust generation in papermaking and converting operations
- exact wet web and dry strength to provide machine runnability
- very fast drainage in the wet end

- low fines to prevent fines build up in the white water and low consistency after wet presses (more steam is consumed in these cases)

The tissue papers and other porous-alike papers demand for loosen fibers in the paper structure. For this reason, fiber bonding is a poison, up to a certain extent. The fibers cannot collapse because this effect will flat the fibers and the paper surface; the paper becomes stronger in tensile, but all the tactile properties will be lost due to sheet compactability. Pulp fines are also undesirable for two reasons: fiber bonding and building up in the paper-machine white water system, reflecting in losses of drainability.

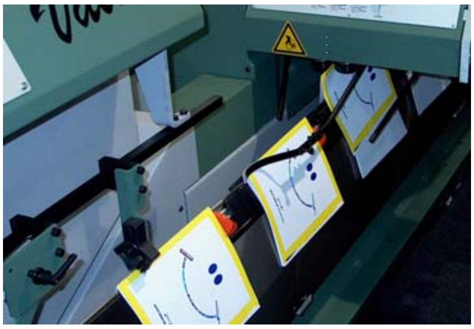
The most indicated eucalyptus pulps for tissue and highly porous paper manufacturing are those showing: low fiber population and consequently high coarseness (for eucalyptus, do not forget), low fines and vessel elements contents, low bonding ability, low fiber collapsibility, low wet fiber flexibility, low hemicellulose content, low extractives and pitch content, low water retention value, thick cell walls, high cell wall fraction, rigid and cylindrical fibers, low unbeaten pulp Schopper Riegler, pulps resistant to the refining (slow beating development).

Fiber deformations are also important, since these deformations improve the bulk, porosity, softness and absorption of these papers. An important issue to remember is that fiber deformations may be artificially created in the pulp mills.

The manufacture of industrial filter papers, and impregnation-based papers are demanding the same properties, but in a higher level. This means, to go to these specialty paper markets, the pulp differentiation must be even more pronounced. The simplest way to work in differentiated pulps to these very specialty markets is to work towards very high coarseness (low fiber population, what means high wood basic density in the wood supply), low hemicellulose content, low fine content (by fractioning fines or removing fines from one paper line and using them in another one, where more desirable) and to intensify fiber deformations (by high consistency presses, fiber shredding, or pulp flash drying).

Another possibility that has feasibility to improve the pulp properties for tissue and highly porous papers is to take advantage of hysteresis. Drying of pulp has very good impact in the WRV, WFF, fiber bonding and fiber collapsibility. Integrated tissue mills have more difficulties to reach the desired furnish and paper properties. A solution is to add some DIP (market deinked pulp) or some percentage of dried market pulp in the furnish, in a percentage that may solve the eventual bottlenecks the mill is facing.

- **Printing & writing papers**



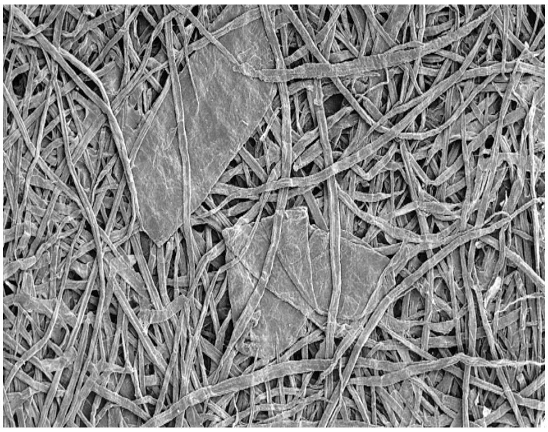
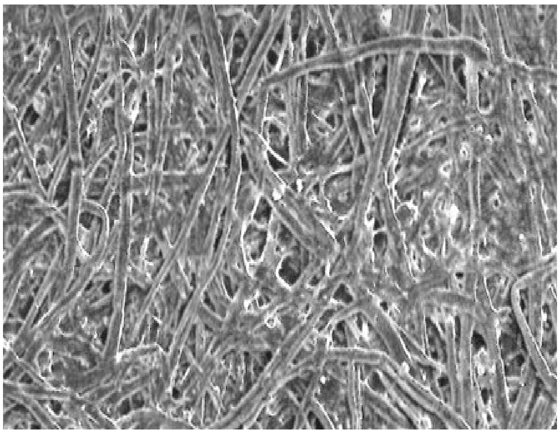
For printing and writing papers, the desirable paper properties are:

- formation
- dry paper strengths (tensile, tear, fold)
- paper internal strength (delaminating in the Z direction)
- paper surface smoothness
- paper surface strength (Scott bonding test or wax pick test)
- good porous structure (porosity or air resistance)
- liquid (ink) absorption properties
- dimensional stability
- opacity
- light scattering coefficient

At the same time, the papermaker wants to keep the machine runnability. We should never forget about the papermaking physiology. A higher fiber population is welcome for improved formation and opacity, associated to lower fiber coarseness. Also, fiber bonding is important to improve strengths. Hemicellulose and pulp fines contents do help in this task. However, there are limits to all this and the limits depend on each paper-machine system and operation. A very high fiber population may be wonderful to improve opacity and formation, but drainage in the wet end and consistency after wet presses may become deteriorated, and machine speed reduced. The papermaker is to refuse this pulp. He wants quality and runnability both aligned, remember this. Fiber deformation here may not be so important, but they may help to balance the pulp properties, since machines may create it. Higher contents of hemicelluloses are welcome because they favor refining, bonding, consolidation of the paper web, and strength properties (tensile, burst, tear, folding).

An ideal pulp should have high strengths at the low levels of refining (fast beating response). This is possible for pulps with high zero span test, a demonstration of strong individual fibers. This situation allows the possibility to have strengths and bulk / porosity / drainage at the same time in the papermaking. The P&W papermaker loves to have a good combination of strengths, bulk, porosity and opacity. The papermaker don’t like to refine a pulp very hardly: he is raising energy costs, reducing the life of refiner discs, and deteriorating machine drainage, machine speed, steam consumption and a very important paper property that is dimensional stability. Definitively, the best pulps are those showing good strengths at low levels of refining. For this reason, an interesting beating test for pulps is the measurement of strengths properties (tensile, tear, stretch) at a given bulk (for example: 1.6 or 1.8 cm^3/g), or at a given sheet density (for example: 0.5 or 0.55 g/cm^3), or at a given freeness level (25, 30 or 35ºSR, depending on the paper grade being produced). P&W papermaker is very sensitive to all these pulp and paper properties.

In addition, there is another wood anatomical characteristic very important to the printing grade papers: vessel elements content and vessel dimensions (specially the vessel diameter). Large, wide and numerous vessels are undesirable for P&W papers. They are responsible for a printing defect known as vessel picking. The papermaker needs to have special conditions to combat the vessel-picking tendency in the paper. For these reasons, a wood with smaller vessels and not so abundant is preferred. The same for the corresponding pulps.

Printing paper surfaces (vessel elements in the left side photo)

- **Specialty papers**

There are many other grades of papers manufactured with eucalyptus pulps: self-copying, cigarette, thermo-facsimile paper, glassine, filters, labels, etc. In most of the cases, the eucalyptus fibers are used to improve paper formation, opacity, smoothness, dimensional stability, bulk and porosity. The eucalyptus fiber population in the pulps, and their rigid and difficult to be collapsed fibers are important properties loved by the papermakers. Eucalyptus pulps are not oriented to be highly refined, unless the papermaker is willing to discard the best properties the eucalyptus pulps have: bulk, porosity, formation, dimensional stability, opacity, softness, and water absorbency. In case of very low coarseness eucalyptus fibers (around 4.5 to 5 mg/100m), the fiber collapsing may become valuable for the manufacture of glassine, bible paper, and other high density papers. This is a clear indication that eucalyptus pulps may offer a variety of fiber qualities, what may make these pulps able for a wide range of utilization's.

There is another key driver to papermakers for using eucalyptus fibers: the market pulp prices of this pulp fiber. Thanks to the low production costs, high pulping yield and lower chemical and wood consumption, these pulps are in general less expensive than softwood pulps. No doubt that production costs are also key issues for papermakers. The same to the entire eucalyptus pulp and paper production chain.

CONCLUSIONS

From all discussions in this Eucalyptus Online Book chapter, it becomes clear that the differences in bleached kraft eucalyptus pulps cannot be attributed solely to the fiber morphology and geometry. There is a number of important properties that together allow one eucalyptus pulp to perform differently than another one. The pulp and paper makers, who are able to understand these interrelationships, may better use the eucalyptus fibers in a magic way.

What can they do to bring an unique reference to their paper products in the competitive market? What important properties on the eucalyptus fibers and pulps should they pay attention to? How can they better select the eucalyptus pulp they may need according to their papermaking process and end-product specifications?

A selected list of some of the important eucalyptus fiber/pulp characteristics and their range of variation for the universe of eucalyptus pulps is presented below. I hope it may help papermakers to search or to identify the ideal pulp to their purposes.

- Fiber population: 12 to 30 million of fibers/gram of pulp
- Fiber coarseness: 4.5 to 11 mg/100m

- Fiber length (weighed): 0.6 to 0.85 mm
- Fiber curl or fiber shape index: 5 to 15%
- Fiber kinks: 0.4 to 1.5 kinks with angle higher than 30º/mm of fiber
- Fiber wall thickness: 2.5 to 5 micrometers
- Fiber wall fraction: 30 to 55%
- Fines (on weight, below 200 mesh, dynamic jar test): 4 to 10%
- Pentosan content (hardwood hemicelluloses): 12 to 22%
- 5% Caustic soda solubility (related to hemicelluloses): 8 to 15%
- Unbeaten pulp WRV (never dried pulps): 150 – 220%
- Unbeaten pulp WRV (dried pulps): 100 – 130 %
- Market pulp pH: 5 to 7.5
- DCM extractive content: 0.05 to 0.25%
- Pulp intrinsic viscosity: 450 to 900 cm^3/g
- Dirt: lower than 2 mm^2/kg
- Zero Span dry: 90 to 160 Nm/g
- Zero Span wet: 70 to 140 Nm/g
- B value (zero span number): 1.5 to 3
- Initial Schopper Riegler (unbeaten pulp): 16 to 24ºSR
- Tensile strength at 25ºSR: 35 to 60 Nm/g
- Tensile strength at 1.6 cm^3/g bulk: 60 to 80 Nm/g
- Bulk at 25ºSR: 1.6 to 2.2 cm^3/g
- Bulk at 60 Nm/g tensile strength: 1.6 to 2.0 cm^3/g
- Air resistance at 60 Nm/g tensile strength: 1 to 10 $s/100cm^3$

Paper product performances, both in paper manufacturing and in the end utilization, demand for high quality pulps. Eucalyptus pulps offers a pathway to higher quality paper products. Eucalyptus pulps have today gained the status of the most admired fiber supply. They are growing in an unbeatable utilization rate in the paper world business. They may be used as the single fiber in the furnish or blended with others, such hardwoods, softwoods, high yield pulps, or recycled fibers. However, there are still a good number of opportunities to even further optimizations in this pulp use. As a simple recommendation, please think about the following issues:

- management of the swelling ability of the furnish;
- management of fines (removal or addition in controlled rates);
- management of fiber deformations (created by specially designed equipment's, as a high consistency pulp shredder);
- management of pulp blends in the furnish (incorporating different pulps with different potentials);
- management of wood supply to the pulp manufacture .

These topics will come in near future as new chapters in our **Eucalyptus Online Book**. Please, wait for the next chapters.

LITERATURE REFERENCES & SUGGESTED READING

Abitz, P.; Luner, P. **The relationship of wet fiber flexibility (WFF) to fiber and pulp properties**. ESPRA Report Nº 94: Chapter V. Syracuse. p. 67 – 87. (1991)

Alexander, S.D.; Marton, R.; McGovern, S.D. **Effect of beating and wet pressing on fiber and sheet properties. I. Individual fiber properties**. Tappi Journal 51(6): 277 – 283. (1968)

Bassa, A.; Bassa, A.G.M.C.; Sacon, V.M.; Valle, C.F. do **Seleção e caracterização de clones de eucalipto considerando parâmetros silviculturais, tecnológicos e de produto final**. II ICEP - International Colloquium on Eucalyptus Pulp. Chile. 20 pages. (2005)
Available at:
http://www.celuloseonline.com.br/imagembank/Docs/DocBank/Eventos/SII_1.pdf

Bertolucci, F.L.G.; Rezende, G.D.; Andrade, G.M.; Claudio-da-Silva Jr., E.; Penchel, R.M.; Demuner, B.J.; Santos, C.A.S. **Tree engineering at Aracruz Celulose – Present perspectives**. Proceedings of the TAPPI Pulping/Process & Product Quality Conference. 9 pages. (2000)
Summary available at:
http://www.tappi.org/s_tappi/doc_bookstore.asp?CID=5157&DID=516665

Campos, E.S.; Martins, M. A .L.; Foelkel, C.E.B.; Frizzo, S.M.B. **Seleção de critérios para a especificação de pastas branqueadas de eucaliptos na fabricação de papéis para impressão offset**. Ciência Florestal 10 (1): 57 – 75. (2000)

Carpim, M.A.; Barrichelo, L.E.G.; Claudio-da-Silva Jr., E.; Dias, R.L.V. **A influência do número de fibras por grama nas propriedades óticas do papel**. Proceedings of the 20th ABTCP Annual Congress. São Paulo. p. 183 - 205. (1987)

Claudio-da-Silva Jr., E. **The flexibility of pulp fibers. A structural approach**. TAPPI International Paper Physics Conference: 13 – 25. (1983)

Clark, J. **Pulp technology and treatment for paper**. Second Edition. Miller Freeman Pub. 877 p. (1895)

Cotterill, P.; MacRae, S. **Improving eucalyptus pulp and paper quality using genetic selection and good organization**. TAPPI Journal 80(6): 82 – 89. (1997)

Cowan, W.F.; Cowan, J.; Foelkel, C. **Z-span testing of eucalyptus bleached pulps obtained by different bleaching sequences**. Proceedings of the 35th ABTCP Annual Congress, São Paulo, Brazil, 11 p. (2002)

Cowan, W.F.; Cowan, J.; Foelkel, C. **Z Spam testing for better papermaking quality pulp**. PowerPoint presentation: 24 slides. (2002)
Available at:
http://www.celso-foelkel.com.br/artigos/Palestras/Z-span%20for%20testing%20pulps.pdf

Dadswell, H.E.; Wardrop, A.B. **Some aspects of wood anatomy in relation to pulping quality and to tree breeding**. Appita 13(5): 161 – 173. (1960)

Dean, G.H. **Objectives for wood fibre quality and uniformity**. "Eucalypt Plantations: Improving Fibre Yield and Quality". Proceedings CRCTHF - IUFRO Conference: 5-9. Hobart. (1995)
Available at:
http://members.forestry.crc.org.au/cgi-bin/doc.pl?doc_id=513

Demuner, B.D.; Vianna Doria, E.L.; Claudio-da-Silva J., E.; Manfredi, V. **The influence of eucalypt fiber characteristics on paper properties**. Proceedings of the TAPPI International Paper Physics Conference: 185 – 196. (1991)

Demuner, B.D.; Vianna Doria, E.L.; Claudio-da-Silva J., E.; Manfredi, V. **As propriedades do papel e as características das fibras de eucalipto**. Proceedings of the 24th ABTCP Annual Congress. São Paulo. p.621 - 641. (1991)

Dinus, R.J.; Welt, T. **Tailoring fiber properties to paper manufacture: recent developments**. Proceedings of the TAPPI Pulping Conference: 815 – 828. (1995)

Dinwoodie, J.M. **The relationship between fiber morphology and paper properties: a review of literature**. Tappi Journal 48(8): 440 – 447. (1965)

Faez, M. **Celulose para papel tissue – Uma ferramenta para desenvolvimento da floresta ao produto final**. Seminário Internacional sobre Papéis Tissue. ABTCP. PowerPoint presentation: 26 slides. (2005)

Foelkel, C. **Qualidade da madeira de eucalipto para atendimento das exigências do mercado de celulose e papel**. Conferência IUFRO sobre Silvicultura e Melhoramento de Eucaliptos. 11pp. (1997)
Available at:
http://www.celso-foelkel.com.br/artigos/32%20final.doc

Foelkel, C. **Eucalypt wood and pulp quality requirements oriented to the manufacture of tissue and printing & writing papers**. Proceedings of the 52nd Appita Conference, Brisbane, Australia (1): 149 – 154. (1998)
Available at:
http://www.celso-foelkel.com.br/artigos/34%20final.doc

Foelkel, C. **Fibras e polpas**. PowerPoint presentation: 30 slides. (2004).
Available at:
http://www.celso-foelkel.com.br/artigos/Palestras/Fibras%20e%20polpas.pdf

Foelkel, C. **Differentiation in market pulp products: is market pulp a commodity product?** PowerPoint presentation: 74 slides. (2005).
Available at:
http://www.celso-foelkel.com.br/artigos/Palestras/Differentiation%20in%20pulps.pdf

Foelkel, C. **Advances in eucalyptus fiber properties and paper products**. III ICEP – International Colloquium on Eucalyptus Pulp. Brazil. 6 pp. (2007)
Available at:
http://www.celso-foelkel.com.br/artigos/outros/Advances%20in%20euca%20fiber.pdf

Foelkel, C.E.B.; Barrichelo, L.E.G. **Relações entre características da madeira e propriedades da celulose e papel**. Proceedings of the 8th ABCP Annual Congress. São Paulo. p.40 - 53. (1975)

Fonseca, M.J.O. **Efeito do cozimento e branqueamento para produção de tissue**. Seminário Tecnologia em Papéis Tissue - Inovações na Cadeia Produtiva. ABTCP Associação Brasileira Técnica de Celulose e Papel. PowerPoint presentation: 11 slides. (2002)

Fonseca, M.J.O. **Propriedades da celulose para tissue**. ABTCP / SENAI Expocelpa Sul. PowerPoint presentation: 25 slides. (2006)

Fonseca, S.M.; Oliveira, R.C.; Silveira, P.N. **Seleção da árvore industrial**. Revista Árvore 20(1): 69 - 85. 1996.

Gatari, J.W. **An experimental analysis of the zero and short span tensile tests**. Chalmers University of Technology, Sweden, M.Sc. Thesis. 36 p. (2003)
Available at:
http://www.md.chalmers.se/EM-Masters/theses/archive/pdf/thesis_joan.pdf

Gonçalves, C. **Fibra de eucalipto para papel tisú**. El Papel. November: 42 - 47. (2001)

Institute of Paper Chemistry. **Characterization of pulps for papermaking. A comparison of some fiber measurement techniques**. Project Report Nº 2406. 58 pp. (1966)

Joutsimo, O.; Wathém, R. ; Tamminen, T. **Effects of fiber deformations on pulp sheet properties and fiber strength**. Helsinki University of Technology. 16 pp. (2004)
Available at:
http://lib.tkk.fi/Diss/2004/isbn9512274450/article5.pdf

Kibblewhite, R.P. **Effects of beating, beaters, and wood quality on the wet web strength.** New Zealand Journal of Forestry Science 5(1): 110 – 118. (1975)

Kibblewhite, R.P. **Product-driven eucalypt fiber selection for papermaking**. II ICEP - International Colloquium on Eucalyptus Pulp. Chile. PowerPoint presentation: 64 slides. (2005)
Available at:
http://www.celuloseonline.com.br/imagembank/Docs/DocBank/Eventos/SI_6.pdf

Kibblewhite, R.P.; Bawden, A.A.; Hughes, M.C**. Hardwood market kraft fiber and pulp qualities**. Appita 44(5): 325 – 332. (1991)

Lehtonen, J. **Influence of commercial hardwood fibers from different production regions on wood free paper properties**. Faserstoff Pulp Technology Symposium. PowerPoint presentation:15 slides. (2005).
Available at:
http://www.glocell.fi/Lehtonen%20Presentation%20FS_503_Brfl.pdf

Lehtonen, J. **Innovation in papermaking furnish and impact on the future use of various pulp fibres**. PTS Munich, GloCell Oy. PowerPoint presentation: 39 slides. (2005)
Available at:
http://www.glocell.fi/Lehtonen_presentation_print.pdf

Lowe, R.; Ragauskas, A.J. **The deformation behavior of wet lignocellulosic fibers**. Institute of Paper Science and Technology / Georgia Institute of Technology. PowerPoint presentation: 42 slides. (no date reference available)
Available at:
http://ipst.gatech.edu/faculty_new/faculty_bios/ragauskas/posters/wet%20fiber%20deformability.pdf

Lundqvist, S.0.; Grahn, T.; Hedenberg, 0.; Hansen, P. **Visions and tools for forest and mill integration. Part 2: Some new approaches under development at STFI for prediction of paper properties**. Eurofiber Seminar, STFI. PowerPoint presentation: 31 slides. (2003).
Available at:
http://www.stfi.se/upload/3439/02_d14-3_stfi-lundqvist2_Part%202x.pdf

Luner, P. **Wet fiber flexibility as an index of pulp and paper properties**. PIRA International Conference on Advances in Refining Technologies. Vol 1: 24 pages. (1986)

McNinch, D.; Shariff, A. **Specialty pulps and specialty papers**. Intertech Specialty Papers Conference, Montreal. PowerPoint presentation: 70 slides. (2001)

Milanez, A.F. **Relações qualidade x efeito: floresta de eucaliptos x celulose x papéis P&W e tissue**. I Seminário sobre Celulose e Papel. Universidade Federal de Viçosa. PowerPoint presentation: 23 slides. (2004)

Milanez, A.F. **Fibras celulósicas para papéis tissue**. III ICEP – International Colloquium on Eucalyptus Pulp. Brazil. PowerPoint presentation: 17 slides. (2007)

Milanez, A.F.; Barth, P.P.O,; Pinho, N.C.; Vesz, J.B.V. **Influência das hemiceluloses nas propriedades óticas e físico-mecânicas da polpa**. Proceedings of the 15th ABCP Annual Congress. 16 pp. (1982)

Mohlin, U.B.; Burman, A.; Soetanto, S. **How fiber dimensions influence refining response and paper properties using acacia and eucalypts as examples.** TAPPI Engineering, Pulping & Environmental Conference. PowerPoint presentation: 27 slides. (2006)

Nishihata, R.T. **Perspectiva do projeto Genoma e sua importância para a qualidade do papel tissue**. Seminário Tecnologia em Papéis Tissue- Inovações na Cadeia Produtiva. ABTCP Associação Brasileira Técnica de Celulose e Papel. PowerPoint presentation: 25 slides. (2002)

Noe, P.; Demuner, B. **A fibra do eucalipto: uma fibra muito especial**. Aracruz Celulose website. (Access on March 2007)
Available at:
http://www.aracruz.com.br/show_prd.do?act=stcNews&menu=true&lastRoot=16&id=124&lang=1

Paavilainen, L. **Influence of morphological properties of softwood fibres on sulphate pulp fibre and paper properties**. Proceedings of the TAPPI International Paper Physics Conference: 383 - 388. (1991)

Paavilainen, L.; Luner, P. **Wet fiber flexibility as a predictor of sheet properties**. ESPRA Report Nº 84: Chapter IX. Syracuse. p. 151 - 172 . (1986)

Palmeiras, L.P.S.; Colodette, J.L.; Magaton, A.S. **Análise comparativa entre vários métodos de quantificação de hemiceluloses de madeira de eucalipto**. III ICEP - International Colloquium on Eucalyptus Pulp. Poster section. 3 pages. (2007)

PAPRICAN . **Microscopy**. PowerPoint presentation: 41 slides. (no date reference available)

Portucel/Soporcel. **The role of eucalyptus fibers in office papers**. ATIP France. PowerPoint presentation: 41 slides. (2003)

Queiroz, S.C.S. **Efeito das características anatômicas e químicas na densidade básica da madeira e na qualidade da polpa de *Eucalyptus***. Universidade Federal de Viçosa. M.Sc. Thesis. 65 pages and 7 annexes. (2002)

Ratnieks, E. ; Foelkel, C. **Uma discussão teórico-prática sobre polpas de eucalipto para a fabricação de papel tissue**. Proceedings of the 29th ABTCP Annual Congress. São Paulo. Brazil. p. 717 – 734. (1996)

Raymond, C. A. **Genetics of *Eucalyptus* wood properties**. Annals of Forest Science 59: 525 – 531. (2002)

Santos, C.R. **Qualidade da madeira e sua influência nas características de papéis de imprimir & escrever e tissue**. Universidade Federal de Viçosa. 45 pp. (2002)

Santos, E.; Schulz, H.; Figueiredo, M. **Papermaking potential of hardwood pulps for decorative paper: a comparative study**. TAPPI Journal 4(8): 20 - 24 . (2005)

Santos, S.R. **Influência da qualidade da madeira de híbridos de *Eucalyptus grandis x Eucalyptus urophylla* e do processo kraft de polpação na qualidade da polpa branqueada**. M.Sc. Thesis. Universidade de São Paulo. ESALQ/USP. 178 pp. (2005)

Steadman, R.; Luner, P. **An improved test to measure the wet flexibility of pulp fibers.** ESPRA Report: Chapter V. Syracuse. p. 69 – 85 (no date reference available)

Steadman, R.; Luner, P. **The effect of wet fibre flexibility on sheet apparent density.** Transactions of the 8th Fundamental Research Symposium. Oxford. Vol 1: 311 – 337. (1985)

Tikka, P. **Pulp quality – not only chemistry**. III International Colloquium on Eucalyptus Pulp. Brazil. PowerPoint presentation: 32 slides. (2007)
Available at:
http://www.celuloseonline.com.br/imagembank/Docs/DocBank/Eventos/430/1TikkaOral.pdf

Wardrop, A.B. **Fundamental studies in wood and fibre structure relating to pulping processes**. Appita 16(3): xv – xxx. (1962)

Wardrop, A.B. **Morphological factors involved in the pulping and beating of wood fibres**. Svensk Papperstidning 65: 17 pages. (1963)

Wardrop, A.B. **Fiber morphology and papermaking**. Tappi Journal 52(3): 396 – 408. (1969)

Wathém, R. **Studies on fiber strength and its effect on paper properties**. Ph.D. Dissertation. Helsinki University of Technology. KCL Communication Report. 98 pp. (2006)
Available at:
http://lib.tkk.fi/Diss/2006/isbn9512285258/isbn9512285258.pdf